

*THE EFFECT OF SIGNED REINFORCEMENT ON RATS'
FIXED-INTERVAL RESPONDING*

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Four experiments examined the effect on rats' response rate of presenting a brief (500 ms) stimulus simultaneously with the delivery of food on fixed-interval (FI) schedules. In Experiment 1, reinforcement signals that were spatially diffuse (both tones and lights) elevated rates of responding, but responding was attenuated by localized visual stimuli. The remaining experiments examined the signal-induced potentiation of responding. In Experiment 2, a tone reinforcement signal potentiated response rates on an FI schedule, but attenuated response rates on a variable-interval (VI) schedule. This difference was obtained even though the overall rate of responding was equated on the two schedules before the introduction of the signal. Signal-induced potentiation of responding occurred over a range of FI values employed in Experiment 3. In Experiment 4, presenting a reinforcement signal when high local rates of response had occurred immediately before reinforcement resulted in potentiated rates of responding on an FI schedule. The opposite effect on response rate occurred when the reinforcement signal followed only low local rates of response. These results indicate that a variety of factors influence the effects of a reinforcement signal. They imply, however, that the local rate of response at the time of reinforcement is a key factor in establishing the nature of the signaling effect.

Key words: reinforcement signal, response learning, fixed-interval, variable interval, multiple schedule, rat

Signaling the delivery of reinforcement by the presentation of a brief (500 ms) stimulus has a variety of effects on response rates. Although a number of attempts have been made to accommodate signaled-reinforcement effects within a single account (e.g., Pearce & Hall, 1978; Reed, 1989; Roberts, Tarpy, & Lea, 1984), it appears likely that these effects are multiply determined (Williams & Heyneman, 1982). Importantly, the impact of a reinforcement signal depends on the nature of the response that it contacts (see Reed, 1991). This relation means that the impact of the signal on the overall response rate may not be predictable in advance of identifying the response that is reinforced. Despite this proviso, some factors are known to influence the effect of a reinforcement signal.

The schedule of reinforcement is one such factor. For example, signaling reinforcement on a variable-interval (VI) schedule leads to lower rates of response than in a condition in which the reinforcer is not signaled (e.g.,

Reed, Doughty, & Bennett, 2001; Sizemore & Lattal, 1978). This is also true on differential-reinforcement-of-low-rate (DRL) schedules (Tarpy & Roberts, 1985). In contrast, signaling reinforcement on variable-ratio (VR) schedules (e.g., Reed, Schachtman, & Hall, 1988a, 1988b) or differential-reinforcement-of-high-rate (DRH) schedules (Reed, 1989; Tarpy & Roberts), leads to high rates relative to an unsignaled condition.

The critical aspect of the schedule in determining the impact of the reinforcement signal appears to be the response that makes contact with the reinforcement signal. For example, on tandem schedules the impact of the signal is determined by the final component of the operative schedule. Thus, on a tandem VI VR schedule, a reinforcement signal potentiates responding relative to an unsignaled condition; whereas, on a tandem VR VI schedule, a reinforcement signal attenuates responding (Reed, 1989). Reed demonstrated that requiring a short interresponse time (IRT) at the end of a VI schedule for reinforcement ameliorates the signal-induced attenuation in responding usually seen on VI schedules. Moreover, requiring that several responses be emitted during a short space of time immediately before reinforcement on a VI schedule leads to a signal-induced poten-

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tiation of responding, similar to that noted on VR and DRH schedules.

These findings suggest that a reinforcement signal enhances learning about the immediately preceding pattern of behavior (Reed, 1989). The immediately preceding pattern, however, may not be determinable in advance of the study. In fact, the pattern of responding that precedes reinforcement may alter over the course of exposure to a free-operant schedule. Marr (1979) noted that a number of initially separate responses (e.g., single lever presses or key pecks) may become "unitized" over time to form larger, but integrated, sequences of behavior that themselves serve as an operant (see also Schwartz, 1984). In support of this view, Reed (1991) demonstrated that a four-response sequence, once trained, would be subject to the same signaled-reinforcement effects as a single response. This was also true for a well-trained DRH schedule response unit. On a simple DRH schedule, signal-induced potentiation of responding occurred, but if that DRH response unit was subsequently reinforced according to a VI schedule; that is, a second-order VI(DRH) schedule is in operation, the rate of emission of the entire DRH unit was attenuated by a reinforcement signal.

Thus, a reinforcement signal appears to produce different effects on responding depending upon the operant. This operant is only identifiable in combination with an analysis of the relation of responding to the reinforcement. This complex pattern of results may have implications for the apparently diverse effects that a signal for reinforcement has on responding generated on a fixed-interval (FI) schedule of reinforcement (cf. Kitaguchi & Nakajima, 1998; Nakajima & Kitaguchi, 1996; Tarpy, Roberts, Lea, & Midgley, 1984). The present experiments sought to clarify the effect of a reinforcement signal on an FI schedule and explore the interaction of the signal with the development of the operant on such a schedule.

EXPERIMENT 1

A variety of signal-induced effects have been observed on FI schedules. Tarpy et al. (1984) noted that a 500-ms localized light stimulus attenuated responding on an FI schedule (although this attenuation was not

as pronounced as the attenuation noted on a VI schedule of reinforcement). This signal-induced attenuation of responding is compatible with a view that FI schedules reinforce relatively long IRTs, and that such long IRTs are promoted by a reinforcement signal, with the result that overall response rate declines.

Signal-induced attenuation of responding, however, is also compatible with the occurrence of sign tracking. A localized light stimulus evokes both orienting and approach in rats, especially if the light predicts the delivery of food (Iversen, 1981). To the extent that the rat is engaged in such sign tracking, lever pressing will decrease. This sign-tracking interpretation of the above results receives support from the findings reported by Nakajima and Kitaguchi (1996). The latter demonstrated signal-induced attenuation on an FI schedule when a light stimulus served as a signal, as had Tarpy et al. (1984), but found when a tone served as a reinforcement signal, potentiation of responding occurred.

The present experiment explored these effects further by investigating whether the different effects on FI response rates produced by using lights and tones as reinforcement signals are due to their sensory modality *per se*. The alternative explanation is that these stimuli produced different effects because of their relative localizability; the light was localizable whereas the tone was more diffuse in nature. To this end, the effects of both localized and diffuse visual stimuli as reinforcement signals were compared with the effects of a tone. If the effect of a reinforcement signal is determined by its modality, then both of the visual stimuli should attenuate responding, whereas the tone should elevate responding. In contrast, if the differing effects are due to stimulus localizability, then the localized visual stimulus should attenuate responding, whereas both the diffuse visual and auditory stimuli should elevate responding.

METHOD

Subjects

Three male Lister hooded rats, naive to the conditions of the experiment, were used. The rats were 3 to 4 months old at the start of the experiment and had free-feeding body-weight ranges of 285 to 340 g. The rats were housed together and were fed to maintain 85% of

their free-feeding body weights. Constant access to water in the home cage was provided.

Apparatus

Three identical operant conditioning chambers were used. The dimensions of the chambers were 26 cm wide by 30 cm long by 23 cm high. Each chamber was located in a sound- and light-attenuating box and was equipped with a ventilation fan that provided a background masking noise of 65 dB(A). Each chamber contained two identical response levers located on each side of a centrally located food tray. The levers were 3 cm long, positioned 3 cm from the wall and the floor, and protruded 2 cm into the box. The levers required a force of 0.06 N to depress them. The food tray was covered by a hinged, clear plastic flap, under which reinforcement (one 45-mg Noyes Formula P food pellet) was delivered. A 24-V fluorescent light was positioned above an opaque white plastic ceiling to provide a diffuse illumination of the chamber. A speaker mounted on the ceiling of the chamber served to deliver a 105 db(A) tone (40 dB above background). The tone was a broad-band, noisy signal (ranging up to 16 kHz) with spectral peaks at 3 kHz and 500 kHz. A localized jeweled houselight (2.5 W) was located centrally above the magazine tray.

Procedure

The rats were trained to retrieve food pellets from the magazine during two 30-min sessions of a random-time (RT) 60-s schedule. Following magazine training, the rats were trained to press levers. They were exposed to a multiple continuous reinforcement (CRF) CRF schedule for three sessions. During one of the components, the light above the left lever was illuminated for 3 min, and only responses to that lever resulted in food delivery. At the end of this 3-min component, a 30-s intercomponent interval (ICI) occurred, during which all lights were extinguished, and no responses were reinforced. Following the ICI, the next 3-min component began. During this second component, the light above the right lever was illuminated and only responses to this lever were reinforced according to the CRF schedule. After this component terminated, another 30-s ICI followed, and then the cycle started again. The cycle repeated

five times per session (i.e., rats were exposed to each lever five times).

Following pretraining, the experimental contingencies were introduced. All rats were exposed to a multiple FI 60-s FI 60-s schedule. During these sessions, a light was illuminated above the left lever for approximately 5 min. The exact termination of the component occurred when the last FI schedule of the component was completed. Responses to the left lever, but not to the right lever, were reinforced according to an FI 60-s schedule. Following this exposure, a 30-s ICI ensued, as described above. The light above the right lever was then illuminated, and a 5-min exposure (programmed as above) to an FI 60-s schedule ensued. This period was followed by the ICI, and then the light over the left lever was illuminated again. Six exposures to each of the two components constituted a session. The components were presented in strict alternation throughout the session. This training lasted for 20 sessions.

Following this training phase, the contingency remained unaltered from that described above, except in one of the components reinforcement was accompanied by the presentation of a 500-ms stimulus (presented simultaneously with the delivery of reinforcement). For Rat 80, this stimulus was the tone, for Rat 81 it was a diffuse light (the fluorescent light), and for Rat 82 the stimulus was a localized light (the houselight). This training continued for 10 sessions.

Training then reverted to the multiple FI 60-s FI 60-s schedule without the reinforcement stimulus for another 20 sessions. For the next 10 sessions, Rat 80 received the diffuse-light reinforcement signal in one component, Rat 81 received the localized light, and Rat 82 received the tone. Following these sessions, all rats were exposed to the multiple FI FI schedule for 20 sessions with no reinforcement signal in either component. For the following 10 sessions, Rat 80 received the localized light as a reinforcement signal in one component, Rat 81 received the tone, and Rat 82 received the diffuse light. Finally, all rats were returned to the baseline contingencies with no reinforcement signal in either component for 20 sessions. The full design is shown in Table 1.

Table 1
Design of Experiment 1.

| Phase | Rat 80 | Rat 81 | Rat 82 |
|-----------|--------------------------|--------------------------|--------------------------|
| Baseline | Mult FI 60-s FI 60-s | Mult FI 60-s FI 60-s | Mult FI 60-s FI 60-s |
| Signaling | Mult FI 60-s (T) FI 60-s | Mult FI 60-s (D) FI 60-s | Mult FI 60-s (L) FI 60-s |
| Baseline | Mult FI 60-s FI 60-s | Mult FI 60-s FI 60-s | Mult FI 60-s FI 60-s |
| Baseline | Mult FI 60-s FI 60-s | Mult FI 60-s FI 60-s | Mult FI 60-s FI 60-s |
| Signaling | Mult FI 60-s (D) FI 60-s | Mult FI 60-s (L) FI 60-s | Mult FI 60-s (T) FI 60-s |
| Baseline | Mult FI 60-s FI 60-s | Mult FI 60-s FI 60-s | Mult FI 60-s FI 60-s |
| Baseline | Mult FI 60-s FI 60-s | Mult FI 60-s FI 60-s | Mult FI 60-s FI 60-s |
| Signaling | Mult FI 60-s (L) FI 60-s | Mult FI 60-s (T) FI 60-s | Mult FI 60-s (D) FI 60-s |
| Baseline | Mult FI 60-s FI 60-s | Mult FI 60-s FI 60-s | Mult FI 60-s FI 60-s |

Note. T = Tone signal; D = Diffuse light signal; L = Localized light signal.

RESULTS AND DISCUSSION

Figure 1 displays the rats' response rates over the last four sessions of each 10-session phase for both components of the multiple FI FI schedule. In all baseline phases, response rates were similar in both components of the multiple FI FI schedule, and these same rates were generally recovered across the baseline phases. All rats displayed typical scalloped patterns of FI performance in all phases. The response rates were lower in the signaled than in the unsignaled component for all rats when the localized light was employed as the reinforcement signal. The opposite was observed, however, for all rats with the diffuse light, and with the tone; that is, signal-induced potentiation of responding was observed with these two stimuli.

These results replicated the previously reported effects for both localized visual and auditory stimuli when these cues are used as reinforcement signals on FI schedules (cf. Nakajima & Kitaguchi, 1996; Tarpy et al., 1984). These effects are probably the result of the localizability of the stimulus rather than its modality. That is, a diffuse visual stimulus produced a similar potentiation effect to the auditory stimulus. This similarity between the diffuse visual stimulus and the auditory stimulus, in respect to their roles as reinforcement signals, previously has been shown for VR schedules (Reed et al., 1988b).

The present findings imply that the effect of a reinforcement signal on an FI schedule depends upon the localizability of the stimulus rather than on its modality per se. The different effect of a localized visual stimulus is most likely due to sign tracking evoked by such a stimulus. This type of stimulus has

been shown to generate orienting behavior (Iversen, 1981), and to interfere with free-operant responding (Reed, 1989). When the likelihood of this type of competing behavior is minimized, by employing diffuse stimuli, then signal-induced potentiation of responding is the result typically observed. This suggests that the signal-induced attenuation of responding on FI schedules reported by Tarpy et al. (1984) might have been the product of competition between sign tracking and lever pressing (see Iversen). Moreover, this effect serves to mask the influence of the processes that enhance responding on FI schedules of reinforcement.

EXPERIMENT 2

The factors leading to the signal-induced potentiation of responding on FI schedules are unclear. That a signal for reinforcement elevates response rate on an FI schedule is difficult for at least two views of signaled reinforcement to explain. The overshadowing view (e.g., Pearce & Hall, 1978) suggests that the signal has a strong predictive relation to reinforcement. In contrast, the response is a relatively weak predictor of reinforcement (being emitted many times without being reinforced). Consequently, the signal would gain strength at the expense of the response, and the rates of response should be lower with signaled than unsignaled reinforcement. The "efficiency" view (Roberts et al., 1984) also predicts lower response rates as a result of signaling reinforcement on FI schedules. It suggests that a reinforcement signal will enhance the efficiency of responding by promoting learning about the temporal contin-

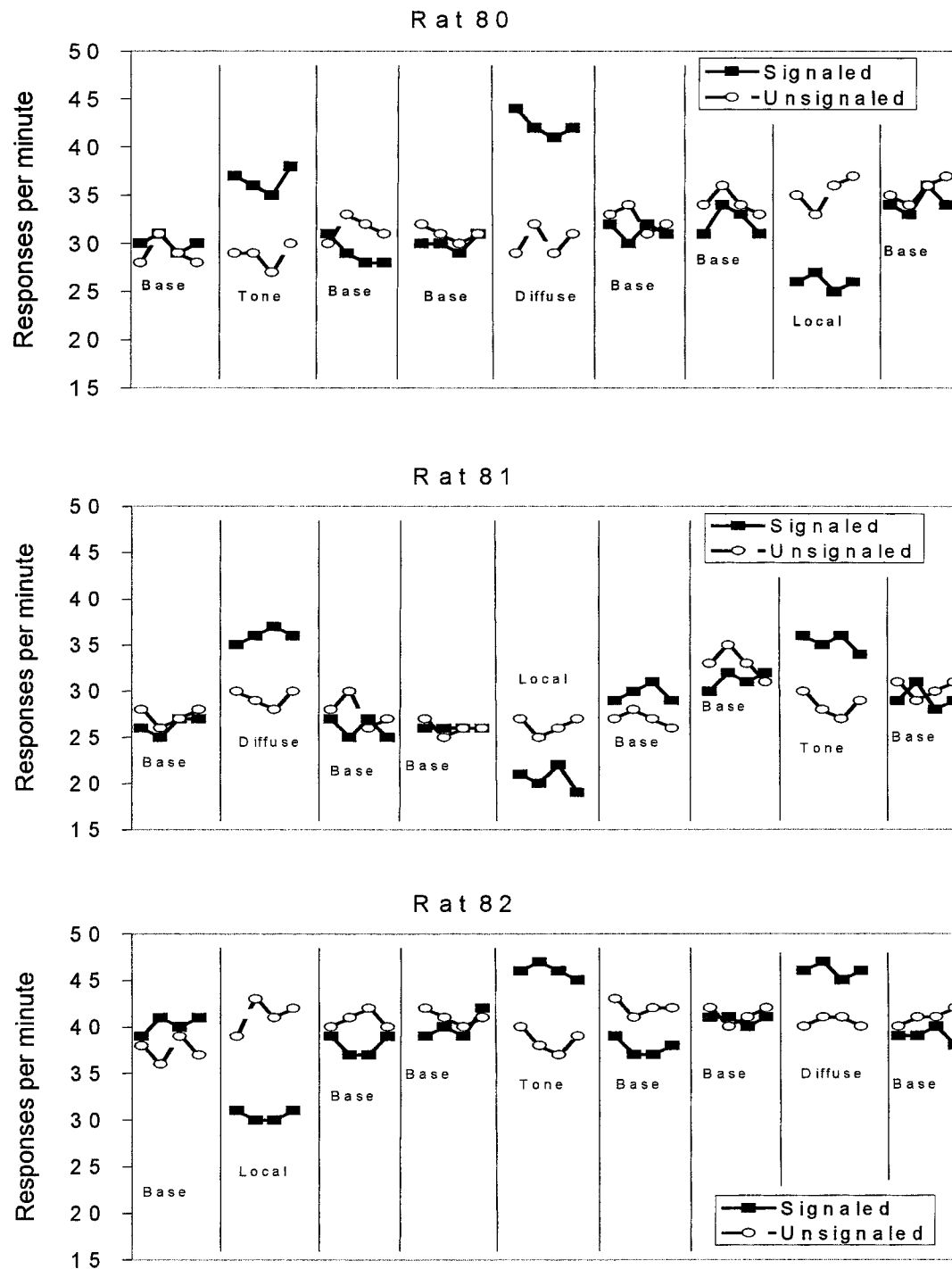


Fig. 1. Results from Experiment 1. Mean response rates over the final four sessions of each phase of the experiment for each rat (see Table 1 for details of phases). All phases involved mult FI 60-s FI 60-s schedules.

gencies in operation, and subsequently will reduce the number of responses emitted per reinforcement. Neither of these views predicts the signal-induced potentiation of responding on FI schedules noted in the first experiment and elsewhere (e.g., Nakajima & Kitaguchi, 1996).

An alternative view of the effects of a reinforcement signal is termed the "response-learning" account (Reed, 1989). This view suggests that reinforcement signals enhance learning about the immediately preceding pattern of behavior and promote its subsequent emission. The predicted effects of a reinforcement signal on responding maintained by an FI schedule according to the response-learning account are not clear, however. The response immediately preceding the reinforcement signal could be defined in terms of a single IRT value. Theoretically, long IRTs have a higher probability of reinforcement than short IRTs on an FI schedule (as is true for VI schedules; see Morse, 1966). If the schedule does differentially reinforce long IRTs, then a signal serving to promote emission of long IRTs would lead to lower overall rates of responding. Response rates tend to increase over the course of the interval on FI schedules, however. This creates the typical scalloped or break-and-run pattern of responding (cf. Cumming & Schoenfeld, 1958; Ferster & Skinner, 1957). Given this, the local rate of response at the time of reinforcement may be reasonably high. In fact, the responding may comprise an extended burst. If the terminal high rate of response is promoted, then a reinforcement signal may lead to an overall potentiation of response rate.

The second experiment explored the potential influence of high *local* rates of response at the time of reinforcement. The effects of signaling reinforcement on FI and VI schedules that have similar overall rates of response to one another were examined. An FI and a VI schedule with similar overall rates of response to one another will present different local rates at the time of reinforcement. This local rate would be higher on the FI schedule than on the VI schedule. On a VI schedule, the rate of responding is reasonably constant over the course of each interreinforcement interval (Leslie, 1982). If the terminal local rates are important in determin-

ing the effect of the signal, then different signal-induced effects are expected on the two schedules. A signal for reinforcement should elevate rate on the FI schedule, where terminal local rates are high. In contrast, the signal should attenuate rates on the VI schedule through the relatively high probability of reinforcement following long IRTs.

Rats were exposed to a multiple VI FI schedule. This schedule was adjusted over the course of the experiment so that the reinforcement rates given in the two components generated approximately equal overall response rates in the two components. Once this was achieved, a brief auditory stimulus was introduced into both components as a reinforcement signal. Given the pattern of results reported previously, response rates should increase in the FI component and decrease in the VI component. These effects, however, could not be attributed to differences in the overall response rate generated by the schedules.

METHOD

Subjects and Apparatus

Three male experimentally naive Lister hooded rats were used. The rats were 3 to 4 months old at the start of the experiment and had free-feeding body weight ranges of 310 to 320 g. The rats were housed and maintained as described in Experiment 1. The apparatus was as described in Experiment 1.

Procedure

The rats were magazine and lever-press trained as described in Experiment 1. Following this training, Phase 1 was introduced. This phase initially consisted of a multiple FI 60-s VI 60-s schedule for all the rats. These sessions comprised approximately 5-min exposures to each component (terminated on completion of the last programmed FI schedule in that component), separated by 30-s ICIs, as described in Experiment 1. Each of the two components occurred six times during a session.

After every four sessions, the rates of response were compared over the two schedules. If the mean VI rate differed from the mean FI response rate by more than two responses per minute over the preceding four sessions, then the VI schedule was altered.

Table 2
Multiple schedule values during Phase 1 of Experiment 2.

| Sessions | Rat 83 | Rat 84 | Rat 85 |
|----------|-----------------|-----------------|-----------------|
| 1-8 | FI 60-s VI 60-s | FI 60-s VI 60-s | FI 60-s VI 60-s |
| 9-12 | FI 60-s VI 55-s | FI 60-s VI 55-s | FI 60-s VI 55-s |
| 13-16 | FI 60-s VI 50-s | FI 60-s VI 50-s | FI 60-s VI 50-s |
| 17-20 | FI 60-s VI 45-s | FI 60-s VI 45-s | FI 60-s VI 45-s |
| 21-28 | FI 60-s VI 40-s | FI 60-s VI 50-s | FI 60-s VI 40-s |
| 29-32 | FI 60-s VI 45-s | FI 60-s VI 45-s | FI 60-s VI 45-s |
| 33-40 | FI 60-s VI 40-s | FI 60-s VI 50-s | FI 60-s VI 40-s |

When the response rate was higher in the VI component than in the FI component, the VI value was increased by 5 s for the next four sessions. When the response rate was lower over the last four sessions in the VI component, the VI value was decreased by 5 s for the following four sessions. The schedules experienced by each of the rats in Phase 1 are shown in Table 2.

Phase 2 training was continued with the VI values reached at the end of Phase 1 (i.e., with a multiple FI 60-s VI x-s schedule). In addition to the above contingencies, a 500-ms tone was presented simultaneously with the delivery of reinforcement in both components. This phase of training continued for 15 sessions. Training then reverted to the multiple FI 60-s VI x-s schedule without the reinforcement stimulus (as in Phase 1) for a further 15 sessions.

RESULTS AND DISCUSSION

The rats' rates of response over the last four sessions in both components of the multiple VI FI schedule are displayed in Figure 2. For all rats, the response rates in the two schedules were similar in the baseline (Phase 1). On the introduction of the signal to both components in Phase 2, response rates decreased in the VI schedule relative to their baseline levels, but increased during the FI component relative to their baseline levels. In Phase 3, the rats' response rates in the two components became similar to one another and recovered their Phase 1 levels. All rats displayed typical scalloped patterns of responding in the FI but not VI components of the schedule.

Figure 2 also displays the rats' response rates over the final 6 s before reinforcement for the final four sessions of each phase of the experiment. These data show that the lo-

cal rates of response immediately before reinforcement were higher in the FI component than they were in the VI component. These terminal local rates of response were similar to the overall rates in the VI component, and they were higher than the overall rates in the FI components.

These data demonstrate opposite effects produced by a signal for reinforcement on VI and FI schedules. The demonstration of different effects on the two schedules replicates, within one experiment, what was apparent from cross-experimental comparisons (cf. Nakajima & Kitaguchi, 1996; Pearce & Hall, 1978). The differing results produced by signaling reinforcement on the two schedules are problematic for many views of the signaled-reinforcement effect. For example, it is clear that the simple versions of both the response-efficiency view (Roberts et al., 1984), and the overshadowing view (Pearce & Hall), cannot accommodate the present results. Each of these theories would predict that the reinforcement signal should reduce rates on both schedules.

Equating response rates on the two schedules before introducing the signal ruled out overall response rate as a determinant of the signaled-reinforcement effects. Rather, the effect of a reinforcement signal must be a function of some other property of the schedule or the behavior that it contacts. One possibility is that the terminal rates of responding determine the effect of the signal.

EXPERIMENT 3

Generating equivalent response rates on the FI and VI schedules required adjusting the reinforcement rates. Higher reinforcement rates were needed to generate similar overall response rates on a VI schedule than

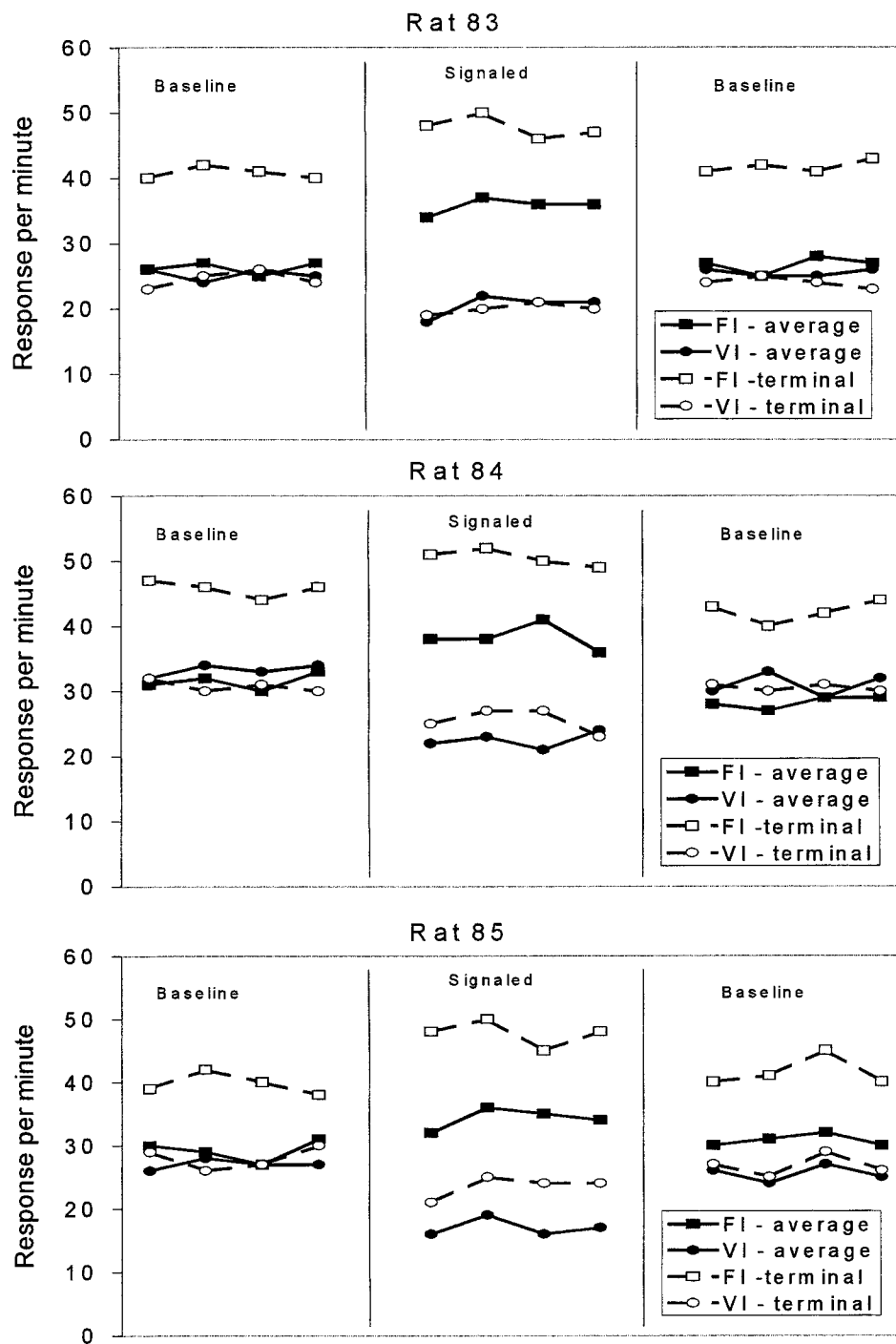


Fig. 2. Results from Experiment 2. Mean response rates over the final four sessions of each phase of the experiment and mean response rates over the final 6 s of each interval for the final four sessions of each phase of the experiment for each rat. All phases involved mult FI VI schedules.

on an FI schedule. This difference between the schedules makes reinforcement rate a potential candidate in generating differential effects of a reinforcement signal. This suggestion would imply, however, that higher reinforcement rates lead to signal-induced attenuation of responding. Response rates were attenuated with a signal on a VI schedule, but were enhanced on an FI schedule, and the former schedule had a higher reinforcement rate than the latter schedule.

This suggestion, however, is not supported by a survey of the existing research on the signaled-reinforcement effect. For example, VR schedules, with a range of reinforcement rates, never produce signal-induced attenuation of responding in rats (Reed & Hall, 1988). Additionally, signal-induced attenuation is found on simple VI schedules despite large variations in reinforcement rate (Reed & Hall). Nakajima and Kitaguchi (1996) found signal-induced potentiation for two different FI schedules of reinforcement, FI 30 s and FI 60 s. The reinforcement rates experienced on these FI schedules overlap with those reinforcement rates used on VI schedules in the present Experiment 2. Taken together, the results of these previous studies make it unlikely that reinforcement rate is the critical variable in the production of reinforcement-signaling effects.

Nevertheless, cross-experimental comparison is always problematic. To further investigate the influence of the rate of reinforcement on the effect of signaled-reinforcement on FI schedules, FI schedules with various rates of reinforcement were studied in Experiment 3.

METHOD

Subjects and Apparatus

Three male Lister hooded rats, naive to the conditions of the experiment, were used. The rats were 3 to 4 months old at the start of the experiment, they had free-feeding body-weight ranges of 305 to 340 g, and they were housed and maintained as described for Experiment 1. The apparatus was as described for Experiment 1.

Procedure

The rats were magazine and lever-press trained as described in Experiment 1. Follow-

ing this training, the experimental contingencies were introduced. These contingencies involved successive exposure to a number of different multiple FI FI schedules. Each multiple FI FI schedule session comprised approximately 5-min exposures to each successive schedule component (terminated on completion of the last scheduled FI schedule in that component). Each component was separated by a 30-s ICI, as described above. Six exposures to each of the two components occurred during a session. The components were presented in alternation. This phase lasted for 20 sessions.

Following this phase of training, the contingency in one of the components was altered so that reinforcement was accompanied by the presentation of a 500-ms tone stimulus (presented simultaneously with the delivery of reinforcement). This training continued for 10 sessions. Training then reverted to the multiple FI FI schedule without the reinforcement stimulus for a further 10 sessions.

This pattern of phases (i.e., baseline-intervention-baseline) was repeated three times for all of the rats. The purpose of this repetition was to expose each animal to all of the FI values employed. Rat 86 experienced FI values in the order 30 s, 60 s, 120 s; Rat 87 experienced them in the order 60 s, 120 s, 30 s; and Rat 88 experienced them in the order 120 s, 30 s, 60 s. These phases are summarized in Table 3.

RESULTS AND DISCUSSION

Figure 3 displays the rats' response rates over the last four sessions for both components of the multiple FI FI schedule. All rats displayed typical scalloped patterns of response in all FI components in all phases of the study. The response rates in the two components were similar to one another for all of the baseline schedule values employed. These response rates were highest in the FI 30-s schedule phase, lowest in the FI 120-s schedule phase, and intermediate in the FI 60-s schedule phase. In the phases that involved the introduction of a reinforcement signal to one component of the multiple schedule, response rates were higher in the signal component than in the no-signal component. This was the case for all rats, irrespective of the FI schedule. The percentage

Table 3
Multiple schedule values during all phases of Experiment 3.

| Phase | Rat 86 | Rat 87 | Rat 88 |
|-----------|--------------------------|----------------------------|----------------------------|
| Baseline | Mult FI 30-s FI 30-s | Mult FI 60-s FI 60-s | Mult FI 120-s FI 120-s |
| Signaling | Mult FI 30-s (S) FI 30-s | Mult FI 60-s FI 60-s | Mult FI 120-s (S) FI 120-s |
| Baseline | Mult FI 30-s FI 30-s | Mult FI 60-s FI 60-s | Mult FI 120-s FI 120-s |
| Baseline | Mult FI 60-s FI 60-s | Mult FI 120-s FI 120-s | Mult FI 30-s FI 30-s |
| Signaling | Mult FI 60-s (S) FI 60-s | Mult FI 120-s (S) FI 120-s | Mult FI 30-s (S) FI 30-s |
| Baseline | Mult FI 60-s FI 60-s | Mult FI 120-s FI 120-s | Mult FI 30-s FI 30-s |
| Baseline | Mult FI 120-s FI 120-s | Mult FI 30-s FI 30-s | Mult FI 60-s FI 60-s |
| Signaling | Mult FI 120-s FI 120-s | Mult FI 30-s (S) FI 30-s | Mult FI 60-s (S) FI 60-s |
| Baseline | Mult FI 120-s FI 120-s | Mult FI 30-s FI 30-s | Mult FI 60-s FI 60-s |

Note. S = Signaled reinforcement.

difference between the components in all phases for all rats can be seen in Table 4.

These results suggest that reinforcement rate cannot explain the difference between the effects of a reinforcement signal on VI versus FI schedules noted in Experiment 2. Potentiation occurred for rates both higher and lower than those of the VI schedules found to lead to signal-induced attenuation of responding in Experiment 2.

EXPERIMENT 4

The final experiment explored the relation between reinforcement signal effects and the local rate of response at the time of reinforcement. If the rate of responding immediately preceding reinforcement is a determinant of the effect of a reinforcement signal, then it should be possible to alter the impact of a signal on overall response rate by manipulating the local response rate it contacts. That is, it should be possible to obtain either signal-induced potentiation or attenuation of responding on the same FI schedule with the same overall rate of response. If the effect of the signal depends on the rate of responding that it contacts, then signals following high local rates should lead to higher overall rates, and signals following low local rates should depress overall response rates.

To assess whether a reinforcement signal interacts with the local rate of response at the time of reinforcement, the reinforcement signal was presented only when the local response rates fell within particular bands. Reinforcement following local response rates falling outside these bands was not signaled. Two bands of local response rate were chosen

in the present experiment: low local rates of response, similar to those emitted on a VI schedule; and high local rates of response, where the rate exceeded the average rate of response noted in the preceding studies.

If the local rate of response at the time of reinforcement is important in producing the effects of a reinforcement signal, then signal-induced potentiation should be observed only when the high local response rates lead to a reinforcement signal. In this case, the signal should differentially promote emission of higher rates of response. In contrast, signal-induced attenuation of responding would be expected when only the low local rates of response lead to signaled reinforcement. In this condition, the signal should differentially promote low rates of response.

METHOD

Subjects and Apparatus

Three experimentally naive male Lister hooded rats were used. The rats were 3 to 4 months old at the start of the experiment and had free-feeding body weights of 310 to 385 g. They were housed and maintained as described in Experiment 1. The apparatus was as described in Experiment 1.

Procedure

The rats were magazine and lever-press trained as described in Experiment 1. Following this training, a multiple FI 60-s FI 60-s schedule was introduced. Each session comprised approximately 5-min exposures to each successive component (terminated when the last FI schedule had been completed), separated by 30-s ICIs, as described above. Six exposures to each of the two com-

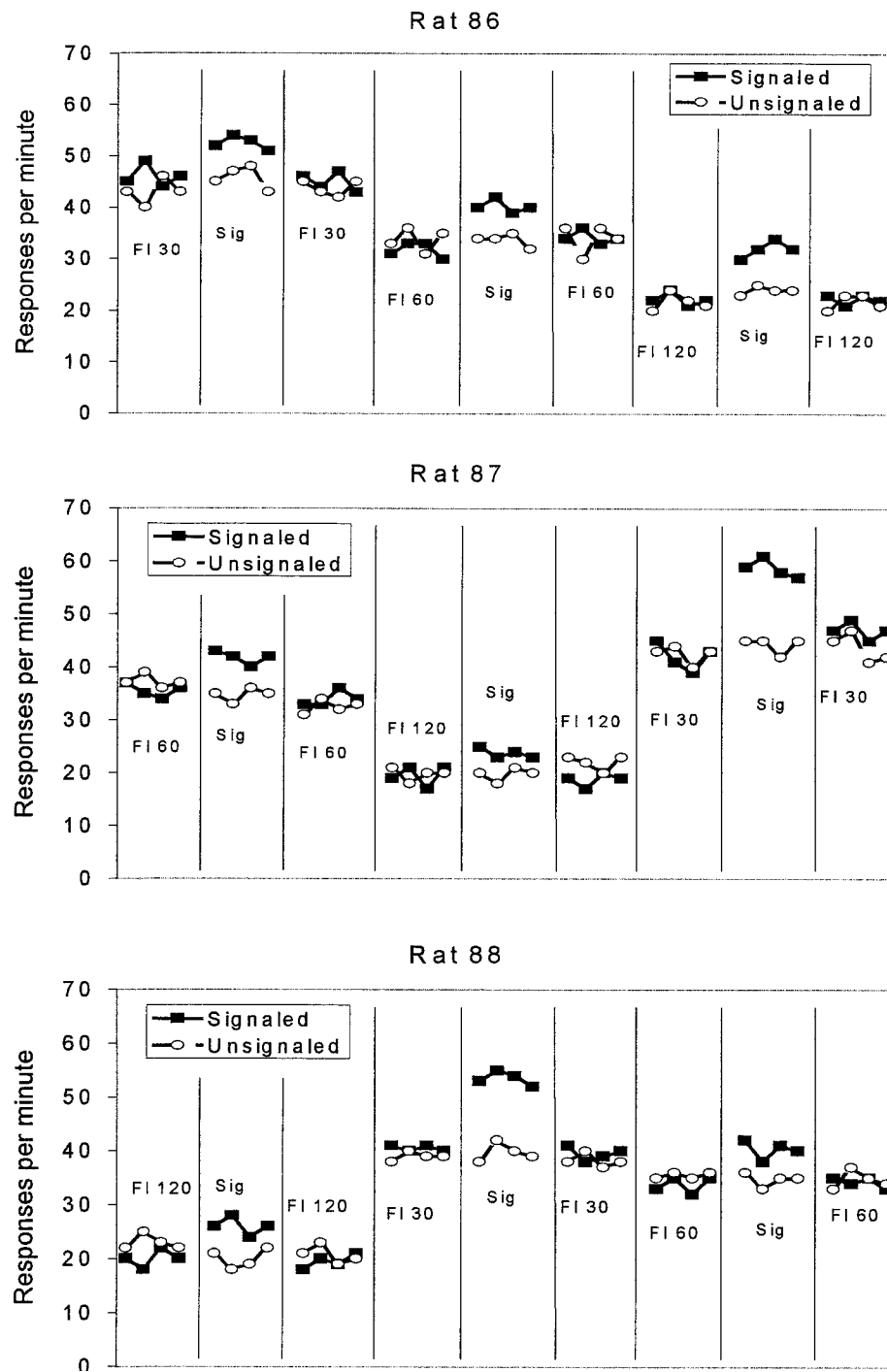


Fig. 3. Results from Experiment 3. Mean response rates over the final four sessions of each phase of the experiment for each rat (see Table 2 for details of phases).

Table 4

Percentage change in both components of the multiple schedules relative to the mean baseline rates for each value.

| Phase | Rat 86 | | Rat 87 | | Rat 88 | |
|------------------------|----------|------------|----------|------------|----------|------------|
| | Signaled | Unsignaled | Signaled | Unsignaled | Signaled | Unsignaled |
| Mult FI 30 s FI 30 s | 14 | 3 | 28 | 1 | 11 | -4 |
| Mult FI 60 s FI 60 s | 19 | 0 | 20 | -4 | 33 | 4 |
| Mult FI 120 s FI 120 s | 27 | 6 | 25 | -8 | 31 | -6 |

ponents occurred during a session, and this training lasted for 20 sessions.

Following this training phase, the contingency was altered so that reinforcement was sometimes accompanied by the presentation of a 500-ms tone (presented simultaneously with the delivery of reinforcement) in both components of the schedule. The requirement for signal presentation was different in the two components. The high-rate component scheduled a reinforcement signal only if the local rate exceeded six responses in the last 6 s of the FI interval. The low-rate component scheduled a reinforcement signal only if the rate fell below two responses in the last 6 s. This training continued for 20 sessions. Training then reverted to the multiple FI FI schedule, without the reinforcement signal, for another 20 sessions.

RESULTS AND DISCUSSION

Figure 4 displays the rats' response rates over the last four sessions of each phase for both components of the multiple FI FI schedule. All rats displayed typical scalloped responding in all FI components in all phases of the study. At the end of the first baseline, rates in the two components were approximately equal to one another, and these rates were recovered in the final baseline. When signals were scheduled, rates of response were higher in the high-rate component, and lower in the low-rate component, relative to the baseline phases. A similar percentage of intervals ended with a signal for both the high-rate and low-rate components. This was true for all of the rats. The mean percentages for the sessions represented in Figure 4 were for the high and low rates respectively: 74% and 63% for Rat 89; 75% and 70% for Rat 90; and, 67% and 70% for Rat 91.

These results demonstrate that the local rate of response at the time of the reinforce-

ment signal is responsible for the effect of that signal. Thus, signaling reinforcement of high local response rates leads to high overall rates. In contrast, signaling the reinforcement of low local response rates leads to lower overall rates. The current finding emerged even though the rates of reinforcement were equated on the two schedules, and the overall rates of responding were initially similar in the two schedules.

GENERAL DISCUSSION

The present experiments explored the effect of signaling reinforcement on FI schedules. This manipulation has been shown to have a variety of effects on response rate. The aim was to isolate the variables that may be responsible for this mixed pattern of results.

In Experiment 1, FI response rate increased when diffuse stimuli were employed as reinforcement signals, but the opposite result occurred when localized light stimuli were employed as reinforcement signals. This finding explains discrepant reports of the effects of reinforcement signals on FI schedules (cf., Nakajima & Kitaguchi, 1996; Tarpay et al., 1984), and suggests that whether the signal is localized or diffuse determines its effect on response rate (see also Reed et al., 1988b).

This pattern of results suggests that sign tracking competes with lever pressing when localized visual cues are used to signal reinforcement (Iversen, 1981; Reed, 1989). When the subject is orienting to the source of the reinforcement signal, this reduces the time available for lever pressing, which, in turn, would reduce the overall rate of lever pressing. Additionally, sign tracking does not have to depend only on the presentation of the light. It could be maintained through classical conditioning, resulting in approach to the source of the conditioned stimulus. Alterna-

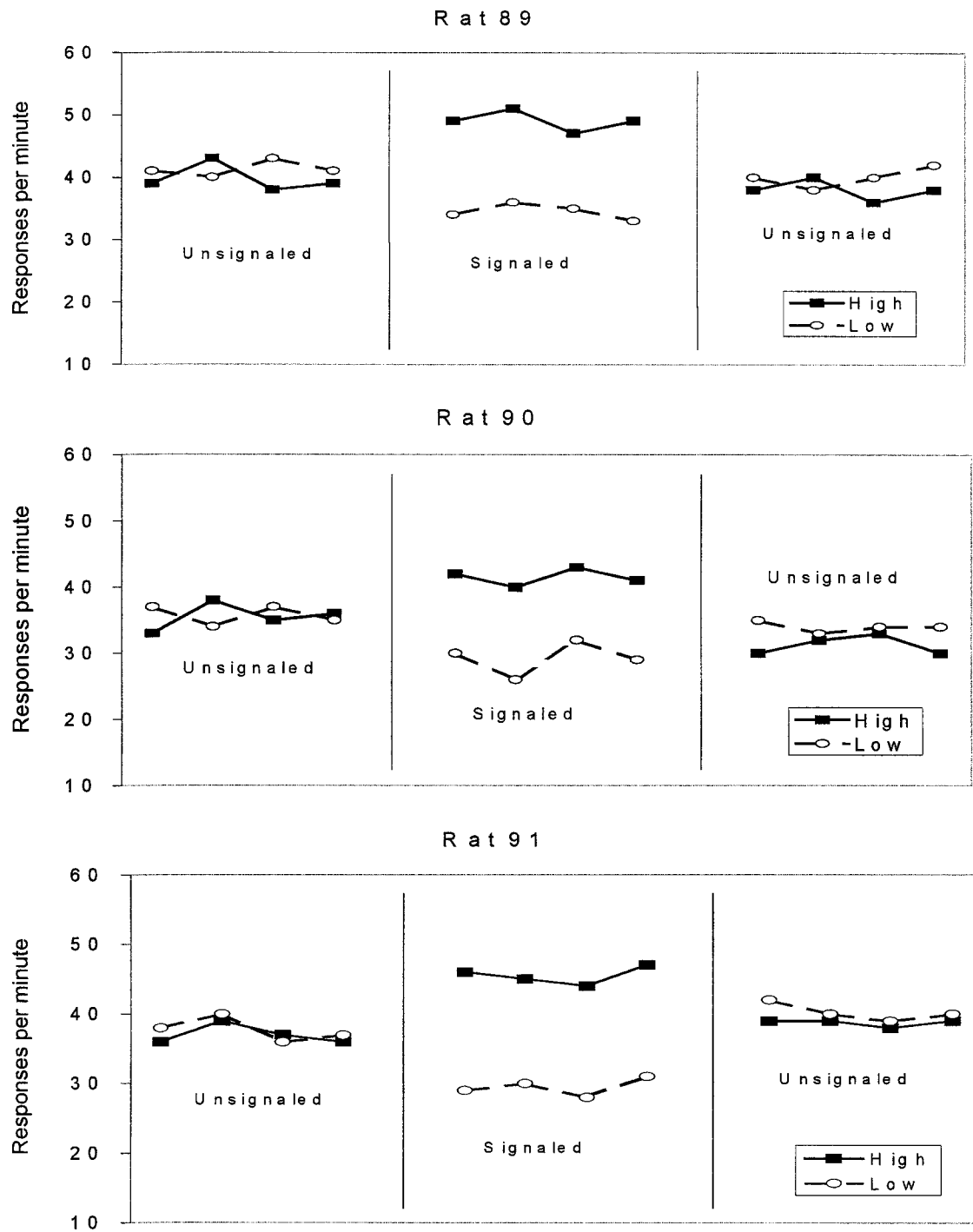


Fig. 4. Results from Experiment 4. Mean response rates over the final four sessions of each phase of the experiment for each rat. All phases involved mult FI FI schedules.

tively, sign tracking may be accidentally reinforced because it occurs simultaneously with the delivery of food. Whichever one of these processes is responsible for the effect of the localized light, it is clear that the type of reinforcement signal used determines whether response rate increases or decreases.

Additional complexity may arise because the nature of the reinforcement signal may have some initial impact on response rate independently of any acquired effects. For example, response-contingent light stimuli appear to have intrinsic reinforcing properties for rats in that they maintain responding independently of any association with primary reinforcement (see Reed, Collinson, & Nokes, 1995). If the light employed as a reinforcement signal is diffuse, then rats' rate of responding may be promoted if it acts as a reinforcer. Although localized lights may also have such reinforcing properties, their association with reinforcement may lead to competing behavior that obscures this reinforcing effect. Tones appear to be aversive initially, irrespective of their association with primary reinforcers or punishers (see Reed & Yoshino, 2001). These aversive properties may suppress responding at first, but these "unconditioned" aversive properties eventually will be overridden by pairing of the tone with reinforcement (e.g., Nakajima & Kitaguchi, 1996).

Although the type of stimulus used as a reinforcement signal may impact behavior, the present results suggest that overall rate of reinforcement is unimportant in determining the effect of a reinforcement signal. Signal-induced potentiation of responding occurred on a variety of FI schedules and, hence, rates of reinforcement.

As the FI schedules in the present study often maintained higher rates of response than VI schedules, overall response rate might seem to be a factor in the signal-induced effects. cursory examination of previous research also is consistent with this suggestion. For example, schedules that produce high rates of responding, such as VR and DRH schedules, produce signal-induced potentiation. In contrast, schedules that produce lower rates, such as VI and DRL schedules, result in signal-induced attenuation of responding. Experiment 2 shows, however, that this cannot be the full explanation of the

signaling effects. In Experiment 2, despite similar overall rates of responding, the signal increased response rate on an FI schedule but decreased it on a VI schedule.

The response-learning view of signaling reinforcement (Reed, 1989) predicts that the effect of a signal depends on the pattern of responding immediately preceding reinforcement. Most responding occurs in the period immediately before reinforcement on an FI schedule, whereas it is distributed evenly across the interval on a VI schedule. This makes it likely that the reinforcement signal would contact relatively high rates of response on the FI compared to the VI schedule. Promotion of high local rates by the signal, according to the response-learning view, would lead to higher overall rates of responding. Thus, on the FI schedule, signal-induced potentiation should occur. That a reinforcement signal can differentially promote particular response rates was demonstrated in Experiment 4. When the signal occurred only for high local rates of responding at the time of reinforcement, potentiation was observed. In contrast, when the signal contacted low local rates attenuation occurred.

Thus, the present experiments point to the importance of the local rate of response at the time of reinforcement as a critical determinant of the signaled-reinforcement effect. Reinforcement signals that contact different local rates of responding will produce different overall rates. This is true even when overall rates of response initially are equated between different schedules (Experiment 2), or when the same type of schedule is employed but the reinforcement signal is made contingent upon different local rates of response (Experiment 4).

Although the present experiments were conducted for a reasonable number of sessions, usually 20 sessions per phase, no explicit stability criteria were used before moving to the next phase of the study. The small variability in each of the terminal performances suggests that the behavior observed in these studies was stable. There was little variability at any point. Nevertheless, this is a post hoc observation. In fact, the adoption of stability criteria, which often require many more sessions to produce stable behavior with FI schedules, might have altered the present findings. One reason for adopting the pres-

ent approach is that the signaled reinforcement effect is typically found during the acquisition of schedule behavior. Often studies of signaled reinforcement use no more than six sessions to produce signal-induced differences in behavior (e.g., Pearce & Hall, 1978). Typically, 20 sessions is the maximum number used in such studies. This might reflect that the signal promotes acquisition of schedule-typical response patterns, and, once stable, the addition of a signal for reinforcement would not produce such an effect. This is an area for further study.

The precise definition of "immediately preceding" is still uncertain, although more than a single IRT would need to be considered as part of the behavioral unit that is reinforced. On an FI schedule, the pattern of responding just before reinforcement is characterized by a relatively high rate compared with a VI schedule. The precise length of IRT reinforced may not be shorter than on the VI schedule, however, because longer IRTs are differentially reinforced on both FI and VI schedules. Reed (1989) noted that requiring a single short IRT be emitted for reinforcement on a VI schedule failed to produce potentiation when reinforcement was signaled. Rather, signal-induced potentiation was noted only when a group of responses had to be emitted in a short space of time after the interval criterion was satisfied (i.e., a tandem VI DRH schedule was in operation). This suggests that reinforcement and reinforcement signals serve to promote emission of the preceding pattern of behavior. Of course, this pattern may change over time as initial patterns are unitized, depending upon the reliability with which they are reinforced. A reinforcement signal appears to strengthen and promote the effects of reinforcement.

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